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Research Article

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Cardiovascular Reactivity to Speech Processing and Cold Pressor Stress: Evidence for Sex Differences in Functional Cerebral Laterality

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Abstract

Traditionally, brain asymmetry has been demonstrated using behavioral measures of laterality. Foremost among these measures has been the evidence for language lateralization to the left hemisphere [14]. The left and right cerebral hemispheres also appear to differ in their parasympathetic and sympathetic nervous system roles, perhaps having direct implications for cardiovascular and cardiopulmonary functioning [14]. The evidence supports a right hemispheric role in activation of the sympathetic nervous system, whereas the left hemisphere is primarily associated with activation of the parasympathetic nervous system. In the present project, sex differences in functional cerebral laterality for processing dichotic speech sounds were examined by measuring cardiovascular reactivity and dichotic listening performance in response to a cold pressor stressor. Men demonstrated a significant increase in systolic blood pressure (SBP) when focusing on sounds at the left ear and in response to the cold pressor stressor. However, the dichotic listening task significantly decreased SBP in men, but not in women. Women demonstrated a unique ability to increase accuracy at the targeted ear and identified significantly more speech sounds at the left ear relative to men. The findings contribute to the literature on sex differences in brain lateralization for language and autonomic nervous system functions that are potentially relevant to differences in cardiovascular risk.

Keywords: Cardiovascular Reactivity; Sex Differences; Laterality; Cerebral Asymmetry; Dichotic Listening; Cold Pressor; Brain Asymmetry.

Cardiovascular Reactivity to Speech Processing and Cold Pressor Stress: Evidence for Sex Differences in Functional Cerebral Laterality

Traditionally, brain asymmetry has been demonstrated using behavioral measures of laterality. Foremost among these measures has been the evidence for language lateralization to the left hemisphere [14]. The left and right cerebral hemispheres also appear to differ in their parasympathetic and sympathetic nervous system roles, perhaps having direct implications for cardiovascular and cardiopulmonary functioning [14,pp441]. The evidence supports a right hemispheric role in activation of the sympathetic nervous system, whereas the left hemisphere is primarily associated with activation of the parasympathetic nervous system.

Increasing evidence from clinical and non-clinical studies suggests that cerebral laterality may play a substantial role in cardiovascular regulation. Clinical studies of stroke victims indicate that right hemisphere stroke may be lead to problems with sympathetic regulation, while left hemisphere stroke may lead to problems with parasympathetic regulation [32,14]. Further, the location of the damage may play a role cardiovascular regulation secondary to a stroke, such that infarction of the right insular cortex may lead to increased cardiovascular problems [32,34].

Lateralization of sympathetic and parasympathetic regulation to the right and left hemispheres is also supported by investigations of non-brain damaged individuals. In a series of experiments, Wittling et al. [43,44] measured autonomic changes in response to lateralized presentation of neutral and emotional films. The authors concluded that sympathetic responses are mediated by the right hemisphere, while parasympathetic responses are mediated by the left hemisphere. Similarly, Hughdahl et al. [22] found that larger changes in heart rate (HR) occurred with right hemisphere presentation of neutral and emotional stimuli relative to left hemisphere presentation of the same stimuli. Further, several studies have indicated that right hemisphere inactivation as a result of intracarotid amobarbital sodium injection increases parasympathetic tone, while left hemisphere inactivation leads

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to increases in sympathetic tone [45,19]. Other studies have investigated the role of hemisphere dominance and cardiovascular regulation. Jaju et al. [23] measured cardiovascular responses in right and left handed individuals. Results indicated that when left handers used their dominant hand to complete a cold pressor test and a hand grip strength test they had increased sympathetic responses relative to right handers using their dominant hands for the same tests. The increased sympathetic response in left handers is thought to be a function of increased right activation as a result of using the left hand [23]. Similarly, individuals with increased hostility, which has been associated with increased right cerebral activation [10,11] also demonstrate increased sympathetic activation in response to stress [10,9,36].

Understanding how functional cerebral laterality contributes to cardiovascular regulation provides potential implications for research examining cardiovascular activity in different populations and how cerebral processing of other tasks can change cardiovascular responses. Specifically, cerebral laterality is hypothesized to vary with sex [30] and may account for sex differences on a number of neuropsychological tasks [40,33]. It follows, then, that cerebral laterality may also contribute to sex differences in cardiovascular regulation. Although research on sex differences has produced controversial data, noted differences in the prevalence, the development, and mortality rates of cardiovascular disease in men and women [1] suggest that there is a true sex difference in cardiovascular regulation. Previous research has reported increased systolic blood pressure (SBP), increased diastolic blood pressure (DBP), or increased reactivity on these measures in men relative to women [38,12,39]. Examination of cerebral laterality provides a possible explanation for these differences. Men are thought to exhibit a higher degree of lateralization relative to women [30]. Heightened lateralization of sympathetic control to the right hemisphere may lead to a decreased ability to control sympathetic responses (i.e. increases in sympathetic tone). Alternatively, this effect may not be present in women if they have bilateral resources for regulation of sympathetic tone. The regulation of sympathetic tone may be further complicated when individuals are confronted with a dual task. Dual task research involves presenting participants with one or more tasks that are reported to measure cerebral function in same brain region (i.e. reading out loud and right finger tapping).

Dual task research has typically been employed to examine manual-verbal interference [13] or cognitive capacity in attention and memory [21]; however, when cardiovascular regulation is conceptualized as a cerebral function dual task research provides an additional approach to understanding how cardiovascular activity is influenced by differential cerebral activation. Kinsbourne and Hicks [27] use 'functional cerebral space' to describe how two processes may interfere with each other. When two tasks compete for the same cerebral resources, the likelihood of performance on both tasks suffering is greater. For example, right-finger tapping interferes with reading out loud [3]. Since both right-finger tapping and reading out loud use left frontal lobe resources, it is hypothesized that execution of the tasks at the same time produces a reduced capacity that leads to decrements in performance. Furthermore, task interference may be related to an individuals degree of cerebral laterality. In a dual task investigation, Lomas and Kimura [29] found that speaking interfered with right hand dowel balancing in men but not in women, indicating a higher degree of language lateralization in men. However, McGowan and Duka [31] failed to find sex differences on a similar manual-verbal interference test. Despite the inconsistent data, the authors state that a lack of interference differences is not necessarily indicative of a lack of lateralization differences. Instead, McGowan and Duka [31] state that men and women may use different cerebral resources based on laterality, but the resources chosen to complete a combination of tasks may still lead to the same amount of overall interference. Further, evidence for sex differences in cerebral laterality have been found on facial affect recognition tasks [17], mental rotation tasks [24], and language tasks [35].

The aim of this experiment was to examine sex differences on a dichotic listening task (a measure of cerebral laterality) and to determine how those differences would influence performance on the task and cardiovascular reactivity to a cold pressor stressor. It was hypothesized that men would demonstrate a higher degree of cerebral laterality for speech sound perception (as evidenced by a greater initial right ear advantage (REA) for dichotic speech sounds) and regulation of SBP, DBP, and HR. This higher degree of laterality was expected to lead to higher reactivity to the cold pressor and differential performance on the dichotic listening task. A sex x focus x experimental condition interaction was expected, where men were expected to evidence heightened accuracy at the left after cold pressor administration. It was also expected that focusing attention to dichotic stimuli at the left would interfere with the regulation of SBP, DBP, and HR in men and result in increased SBP, DBP, and HR reactivity. In contrast, women were hypothesized to be less lateralized for speech sound perception and regulation of SBP, DBP, and HR. As such, it was hypothesized that women would show less cardiovascular reactivity and increased accuracy at either the left or right ear (depending on which focus group they are assigned to) after cold pressor administration. Thus, regulating SBP, DBP, and HR after exposure to the cold pressor was not expected to interfere with women's performance on the dichotic listening task.

Method

Participants

Sixty men and sixty women ranging in age from 18 to 24 years were recruited from undergraduate psychology courses. Participants completed a prescreening consisting of a Head Injury/Medical History Questionnaire, the Coren, Porac, and Duncan Laterality

Questionnaire, the Cook Medley Hostility Scale [5] and the Marlowe-Crowne Social Desirability Scale [7]. Criteria for inclusion included no prior head injury or neurological problems, a clean mental and physical health history, and right handedness. The Cook Medley Hostility Scale and the Marlowe-Crowne Social Desirability Scale were included in order to explore further subject variables that might be related to cardiovascular reactivity and there were no scoring criteria for these measures. Participants were given extra credit for their psychology course in exchange for participation.

Self Report

Head Injury/Medical History Questionnaire. The Head Injury/ Medical History Questionnaire is an 18 item inventory assessing current or previous head trauma or neurological problems. The inventory also assesses current and previous physical and mental health problems. Only participants who reported no current or previous head or health problems were included in the experiment.

Coren, Porac, and Duncan Laterality Test. This self-report, behaviorally validated questionnaire measures left or right hemibody preference. The questionnaire consists of 13 items assessing lateral preference for hand, foot, eye, and ear. Items are scored +1 for right, -1 for left, and 0 for both. Scores range from +13 to -13, indicating extreme right or left handedness. A score of +7 was required for further participation in the experiment.

Cook Medley Hostility Scale. The Cook Medley Hostility Scale is a 50 item inventory that assesses cynicism, anger, suspiciousness, and resentment within the hostility construct. Its validity as a predictor of medical and psychological outcomes has made it one of the more commonly used measurements of hostility [4]. The scale is significantly associated with coronary heart disease and hostile personality type [2,41,42]. It was included in the current experiment in order to gather data for a follow-up experiment and to help explore further participant variables that might influence the results.

Marlowe-Crowne Social Desirability Scale. The Marlowe-Crowne Social Desirability Scale consists of 32 items and identifies individuals who depict themselves in a favorable way or who want to be seen in socially-desirable terms. Crowne and Marlowe [8] indicated that the questionnaire has a .88 test-retest correlation. The scale was used to gather additional descriptive data about the participants.

Apparatus

Cold Pressor. Ice water for the cold pressor was maintained at 0 degrees Celsius using a small ice cooler (Coleman Corporation, model 5274). Water temperature was measured using a standard mercury thermometer (Fisher Scientific, model 14-985E).

Dichotic Listening. A computer-synthesized audio compact disc created by the Kresge Hearing Research Laboratory was used for the dichotic listening task. It consisted of 30 pairs of concurrently voiced consonant vowels (C-Vs; BA, DA, GA, KA, PA, TA). Stimuli were presented at about 75dB by a Sony High Density Linear Converter compact disc player (model CDP-211) using Koss Digital Ready Stereo Headphones (Pro Model 4X Plus). The inter-stimulus interval was 6 seconds. The six C-V pairs were laser printed as 1 cm bold, black upper-case letters on 21.5 cm by 28 cm white paper and displayed approximately 50 cm in front of the participant.

Physiological

Systolic blood pressure, DBP, and HR were measured using a Korotkoff sound measuring device. The procedures adhered to the basic requirements of the American National Standard Institute (ANSI), the Association for the Advancement of Medical Instrumentation (AAMI), and the American Heart Association [15,18]. The accuracy of the HR readings was reported to be within 2% of those gauged (approx. 1 beat/min). The accuracy of the BP measurement was reported to be ±3 mm Hg of those auscultated.

Procedure

Participants who meet selection criteria were invited to the lab for participation. Upon arrival they completed an Informed Consent and were seated in the testing chamber. The testing chamber consisted of a black chair in a sound attenuated room. The cold pressor equipment was also located within the testing chamber. The experimenter was located in an adjacent laboratory room with the equipment for administering the dichotic listening task and recording SBP, DBP, and HR. Participants were assigned to one of the following three groups: the no focus group (NO), the focus left group (FL), or the focus right group (FR). Participants were assigned in a rotational fashion within each sex until each group consisted of 20 participants. The experiment consisted of three phases: pre-stress, stress, and post-stress.

Pre-stress

The BP and HR apparatus were attached to the participant's upper right arm. The experimenter than said the following, "Please make yourself comfortable, try to relax, and sit still in the chair." Next the participant was fitted with the dichotic listening headphones.

After a 1 minute baseline period, SBP, DBP, and HR were recorded. Following this initial measurement, the dichotic listening task began. A brief training phase was conducted in order to introduce the dichotic listening task and to assess participant hearing.

The experimenter read aloud and pointed to each of the six phonemes on the stimulus sheet and asked the participant to repeat each phoneme. Ten C-V pairs were then presented (5 individually at each ear) via the above equipment. In order to continue participating in the experiment participants were required to correctly identify all 10 pairs. The participant was asked to identify the C-Vs by pointing to the phonemes on the stimulus sheet. The experimenter exited the room after the training phase and participants in the NO group heard the following instructions:

Now you are going to hear 30 trials of these syllables. You will hear a syllable in one ear and a different syllable in the opposite ear. It will be somewhat confusing. You need to listen very carefully and point to the syllable on the chart that you hear most clearly.

Participants in the FL group heard the following instructions: Now you are going to hear 30 trials of these syllables. You will hear a syllable in one ear and a different syllable in the opposite ear. It will be somewhat confusing. You need to listen very carefully and point to the syllable on the chart that you hear most clearly in your *left* ear.

Participants in the FR group heard the following instructions: Now you are going to hear 30 trials of these syllables. You will hear a syllable in one ear and a different syllable in the opposite ear. It will be somewhat confusing. You need to listen very carefully and point to the syllable on the chart that you hear most clearly in your right ear.

Following the initial instructions, the recording continued with the presentation of all 30 trials in all groups. The experimenter recorded the participants' response to each trial. After completion of all 30 trials, the experimenter said the following: "Please make yourself comfortable, try to relax and sit still in the chair." Next, SBP, DBP, and HR were recorded again.

Stress

After completion of the first dichotic listening task, participants entered the stress phase, where they were required to submerge their left hand in the ice water. The experimenter marked the participants' arms 1" above the wrist with a black wax pencil. Participants were required to submerge their arm in the ice water up to the mark. The experimenter gave the following instructions to signal the beginning of the cold pressor phase:

Please keep your eyes closed. When instructed, place your left hand in the ice water on your left to the wax line on your wrist. You will be asked to keep your hand in the water for 45 seconds. Although this may be difficult and possibly painful, please try to keep your hand in the water until instructed to take it out. However, you can take your hand out at anytime without any penalty. This test has been used often as a research tool and many research participants have been able to keep their hand in the water for up to 15 minutes without any problems. Do you have any questions? Okay, begin.

After 45 seconds, the participant was asked to remove his or her hand from the ice water.

Post-Stress

Following the cold pressor, participants were told the following, "Please make yourself comfortable, try to relax, and sit still in the chair for a few more minutes." Physiological measures were recorded for the third time. Participants were then administered the dichotic listening task again. The task was administered according to the procedures outlined in the pre-stress phase. Physiological measures were recorded at the end of the dichotic listening task in the same manner as well.

At the end of the experiment, participants rated the level of stress and pain that they experienced from the cold-pressor. The scale was a 7 point scale, where 1 = not stressful at all, 4 = moderately stressful, and 7 = extremely stressful. Following this measure, participants were debriefed and allowed to leave the lab.

Results

Self Report

Laterality Scale*:* Separate t-tests were performed on data from the self report measures to determine if the groups differed at the onset of the experiment. There was no significant sex difference between mean scores on the Coren, Porac, and Duncan Laterality Questionnaire (men - M = 10.3, SD = 2.0; women - M = 11.0, SD = 2.3) (t (118) = -1.73, p<.09).

Cook Medley Hostility Scale: On the Cook Medley Hostility Scale, men scored significantly higher (M = 20.4, SD = 7.2) than women (M = 17.3, SD = 6.9) (t (118) = 2.38, p <.02).

Marlowe-Crown Social Desirability Scale: Groups did not significantly differ on the Marlowe-Crown Social Desirability Scale (men - M = 14.7, SD = 4.7; women - M = 16.3, SD = 5.7) (t (118) = -1.66, p <.10).

Physiological Data

Independent analyses of variance (ANOVA) were performed on SBP, DBP, and HR. Tables 1, 2, and 3 present the means and standard deviations for SBP, DBP, and HR across sex, focus group, and trial. Two design sequences were used in the analysis. The first sequence was collapsed across all focus groups resulting in a sex (men, women) x focus (NO, FL, FR) x trial (pre-stress dichotic listening trial 1, post-stress dichotic listening trial 1, pre-stress dichotic listening trial 2, post-stress dichotic listening trial 2) mixed design ANOVA.

A main effect for sex was found for SBP (F(1, 114) = 46.04, p<.0001) and DBP (F(1,114) = 27.74, p<.0001), but not for HR. Men evidenced significantly higher SBP than women. However, women evidenced significantly higher DBP than men.

A main effect of focus was found only for DBP (F(2, 114) = 3.73, p <.0271). The FR and FL groups had significantly lower DBP than the NO groups, but did not differ from each other.

A main effect of trial was found for SBP (F (3, 342) = 75.85, p <.0001), DBP (F (3, 342) = 14.54, p<.0001), and HR (F (3, 342) = 6.76, p <.0002). Systolic blood pressure decreased significantly between the baseline measurement and the measurement directly after the first trial of dichotic listening. The cold pressor significantly increased SBP; however, systolic recovery from the cold pressor was noted by a significant decrease in SBP after the second dichotic listening trial. Diastolic blood pressure changes underwent a similar pattern. There was no change in DBP between baseline and post dichotic listening trial 1; however, there was a significant increase in DBP after the cold pressor. This was followed by a significant decrease in DBP post dichotic listening trial 2. Changes in HR were inversely related to the changes in SBP and DBP. Heart did not change between baseline and post dichotic listening trial 1, decreased after the cold pressure and then increased post dichotic listening trial 2.

No other significant effects were found, thus refined ANOVAs were performed on each sex. For men, a main effect of focus on SBP was found (F(2, 57) = 4.39, p<.017). The right focus group exhibited a significantly lower SBP than the focus left participants. A main effect of trial on SBP was found for men (F(3, 171) = 52.25, p<.0001) and women (F(3, 171) = 26.44, p<.0001). However, the changes were different for each sex (Figure 1).

	Men		Women	
	Mean	**SD**	**Mean**	**SD**
No Focus Group				
Baseline (Cond 1)	125.1	14.3	110.5	12.0
Post Dichotic 1 (Cond 2)	120.8	11.8	109.7	12.5
Post Cold Pressor (Cond 3)	134.4	13.1	119.9	12.5
Post Dichotic 2 (Cond 4)	121.8	11.2	109.8	10.8
Focus Left Group				
Baseline (Cond 1)	132.0	10.5	113.8	10.2
Post Dichotic 1 (Cond 2)	127.0	8.7	112.3	8.5
Post Cold Pressor (Cond 3)	140.4	12.8	117.8	9.8
Post Dichotic 2 (Cond 4)	127.2	10.0	111.9	8.9
Focus Right Group				
Baseline (Cond 1)	121.3	11.9	114.2	14.1
Post Dichotic 1 (Cond 2)	117.6	10.5	110.0	10.6
Post Cold Pressor (Cond 3)	128.7	14.7	121.6	14.9
Post Dichotic 2 (Cond 4)	119.7	11.2	111.6	10.4

Table 1. Means and standard deviations for SBP by sex, focus group, and condition.

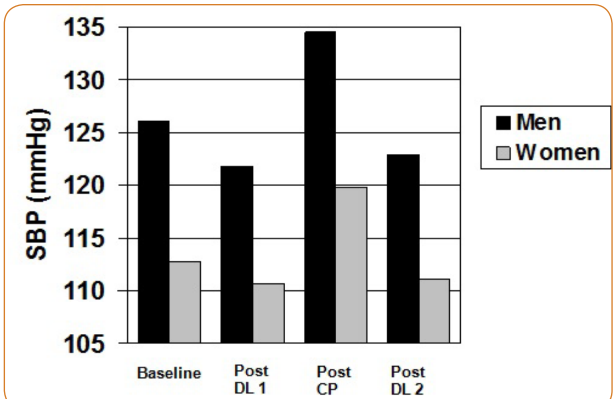

Figure 1. Sex differences in Systolic Blood Pressure (mmHg) as a function of Condition (Baseline, Dichotic Listening 1, Cold Pressor, and Dichotic Listening 2).

	Men		Women	
	Mean	SD	Mean	SD
No Focus Group				
Baseline (Cond 1)	70.2	8.0	77.0	9.3
Post Dichotic 1 (Cond 2)	68.7	6.9	76.6	9.3
Post Cold Pressor (Cond 3)	75.3	11.4	80.3	6.6
Post Dichotic 2 (Cond 4)	70.5	7.4	79.5	7.5
Focus Left Group				
Baseline (Cond 1)	67.7	11.6	75.3	8.6
Post Dichotic 1 (Cond 2)	67.6	9.9	75.0	7.4
Post Cold Pressor (Cond 3)	67.2	13.4	80.7	9.2
Post Dichotic 2 (Cond 4)	66.1	11.5	72.9	9.7
Focus Right Group				
Baseline (Cond 1)	64.4	12.1	71.7	6.8
Post Dichotic 1 (Cond 2)	63.9	9.7	71.3	7.8
Post Cold Pressor (Cond 3)	70.3	10.9	77.0	12.1
Post Dichotic 2 (Cond 4)	67.6	8.0	73.9	7.7

Table 2. Means and standard deviations for DBP by sex, focus group, and condition.

	Men		Women	
	Mean	SD	Mean	SD
No Focus Group				
Baseline (Cond 1)	65.9	13.9	68.3	9.9
Post Dichotic 1 (Cond 2)	66.0	8.6	69.1	11.1
Post Cold Pressor (Cond 3)	63.1	8.7	67.1	9.8
Post Dichotic 2 (Cond 4)	66.1	8.1	68.7	10.9
Focus Left Group				
Baseline (Cond 1)	62.1	7.5	66.1	13.8
Post Dichotic 1 (Cond 2)	62.6	8.7	66.6	12.4
Post Cold Pressor (Cond 3)	60.7	11.1	61.0	12.8
Post Dichotic 2 (Cond 4)	60.6	8.3	64.5	11.7
Focus Right Group				
Baseline (Cond 1)	63.8	10.2	65.0	14.6
Post Dichotic 1 (Cond 2)	67.7	12.5	64.7	13.7
Post Cold Pressor (Cond 3)	63.4	10.1	60.8	12.8
Post Dichotic 2 (Cond 4)	65.0	9.6	64.7	15.1

Table 3. Means and standard deviations for HR by sex, focus group, and condition.

Men experienced a significant decrease in SBP between baseline and post dichotic listening trial 1; however, women's SBP stayed the same between these two measurements. Additionally, the cold pressor significantly increased SBP in both men and women. Significant decreases in SBP were found between administration of the cold pressor and post dichotic listening trial 2 for both sexes.

A main effect of trial was present for DBP in both men ($F(3, 171) = 5.69$, $p<.0010$) and women ($F(3, 171) = 9.12$, $p<.0001$). However, no sex differences in DBP changes were noted.

For HR, no significant effects were found for men. In contrast, a significant main effect of HR was found for women ($F(3, 171) = 6.46$, $p<.0004$). Heart rate significantly decreased after the cold presssor.

To provide a more accurate comparison of the FL and FR groups, a second sequence of analyses was preformed. The following three-factor mixed design ANOVA was used: sex (men, women) x focus (FL, FR) x trial (pre-stress dichotic listening trial 1, post-stress dichotic listening trial1, pre-stress dichotic listening trial 2, post-stress dichotic listening trial 2).

A main effect of sex was found for SBP ($F(1,76) = 32.74$, $p<.0001$) and DBP ($F(1,76) = 17.36$), but not for HR. Men evidenced significantly higher SBP, while women evidenced significantly higher DBP.

A main effect of focus was found only for SBP ($F(1,76) = 4.56$, $p<.0359$). The FR group had the lowest SBP. This is in contrast to the finding from all three focus groups where DBP was the only measure affected by different focus conditions. However, it is similar to the finding among men where focus affected only SBP.

A main effect of trial was found for SBP ($F(3,228) = 43.80$, $p<.0001$), DBP ($F(3, 228) = 9.00$, $p<.0001$), and for HR ($F(3, 228) = 5.79$, $p<.0008$). These cardiovascular changes were similar to those seen in the analysis of all three groups (detailed above).

Perhaps the most interesting finding from the second sequence of analysis was a sex x focus interaction for SBP ($F(1, 17) = 5.37$, $p<.023$) (Figure 2). For men, significant changes in SBP were found between the FL and FR groups; however, women's SBP remained stable between groups.

An additional focus x trial interaction was found for DBP ($F(6, 228) = 3.21$, $p<.0240$). The FR group significantly increased their DBP after the cold pressor; however, the FL group's DBP remained relatively stable across trials. A subsequent analysis of each sex revealed that this was primarily due to men. A significant focus x trial interaction for DBP ($F(3, 114) = 3.42$, $p<.020$) was found in men but not in women.

The analyses of each sex separately revealed additional differences. For men, a main effect of focus ($F(1, 38) = 9.37$, $p<.004$) and trial

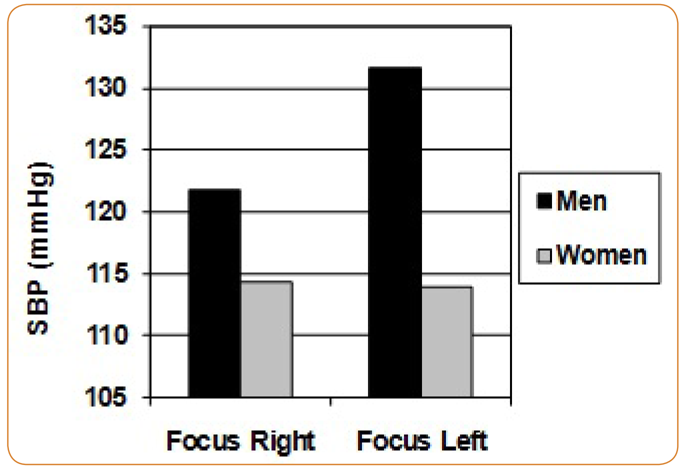

Figure 2. Sex differences in Systolic Blood Pressure (mmHg) as a function of focused intention to the left or the right ear.

($F(3, 114) = 33.00$, $p<.0001$) was found for SBP. Men in the FR group had significantly lower SBP than men in the FL group. Focus group did not affect SBP for women. However, a main effect of trial was found ($F(3, 114) = 13.80$, $p<.0001$). Trial also significantly influenced DBP for women ($F(3, 114) = 7.60$, $p<.0001$).

No significant effects were found for HR in men; however, a significant main effect of trial on HR was found for women ($F(3, 114) = 9.40$, $p<.0001$). Heart rate in women significantly decreased after administration of the cold pressor.

Percentage of Correct Responses

To assess the number of correct responses by each participant a percentage of correct responses (POC) index was calculated. The following formula was used:

$$POC = (pR - pL) / (pR + pL)$$

where: pR = proportion of correctly identified right-ear stimuli
pL = proportion of correctly identified left-ear stimuli

POC scores fall within a range of +1 (right ear advantage, a perfect score) to -1 (left ear advantage, a perfect score; see Table 4 for means and standard deviations of POC scores by sex, focus group, and trial). The data were again analyzed using two different design sequences.

The first design was a sex (men, women) x focus (NO, FL, FR) x trial (pre-stress dichotic listening trial 1, post-stress dichotic listening trial1, pre-stress dichotic listening trial 2, post-stress dichotic listening trial 2) mixed design ANOVA. A main effect of sex was found on POC scores, where men evidenced a significantly higher percentage of correct responses at the right ear than women ($F(1,114) = 4.29$, $p< 0.041$). This suggests greater language laterality (in the left hemisphere) in men, compared to women.

	Men		Women	
	Mean	SD	Mean	SD
No Focus Group				
Pre-Stressor	0.24	0.34	0.10	0.21
Post-Stressor	0.27	0.30	0.17	0.25
Focus Left Group				
Pre-Stressor	0.24	0.24	0.04	0.36
Post-Stressor	0.23	0.30	0.08	0.32
Focus Right Group				
Pre-Stressor	0.22	0.31	0.23	0.18
Post-Stressor	0.30	0.26	0.30	0.16

Table 4. Means and standard deviations of POC scores by sex, focus group, and trial.

A main effect of trial was also found (F (1,114) = 6.15, p < 0.015) where percent correct increased at the right ear following the cold pressor. It is interesting to note that increased accuracy occurred following the cold pressor, which possibly created a compartmentalized arousal phenomenon. Thus, the stressor increased accuracy at the right, but not left, ear for the combined focus groups.

Refined ANOVAs were performed for each sex. Women were found to evidence a main effect of focus (F(2,57) = 3.73, p < 0.030). Thus, women in the no focus (NO), focus left (FL), and focus right (FR) groups were seemingly able to shift their focus to the left ear or to the right ear to the degree that they significantly changed the percent of correct scores at each ear. A main effect of focus on POC scores was not found for men. In fact, men seemed to have difficulty overcoming the right ear advantage that characterizes their language abilities being lateralized in the left hemisphere.

For women, a main effect of trial was also found (F(1,57) = 4.81, p < 0.032) where the percent of correctly identified stimuli increased significantly at the right ear after cold pressor exposure. Again, this effect was not found in men. However, it is possible that a ceiling effect exists in the men's POC scores, which prevents them from increasing already high positive POC scores (indicating a significant right ear advantage), as men evidenced high POC scores across all groups and trials.

The second design was a sex (men, women) x focus (FL, FR) x trial (pre-stress dichotic listening trial 1, post-stress dichotic listening trial 1, pre-stress dichotic listening trial 2, post-stress dichotic listening trial 2) mixed design ANOVA. This series of analyses was conducted more accurately compare the influences of focused attention.

A main effect of focus on POC scores was found, where the FL and FR groups were able to significantly increase accuracy at the left ear and right ear, according to the focus group to which they were assigned (F(1,76) = 4.13, p < 0.046).

Refined analyses of variance were then performed on the men and on the women of the FL and FR groups in order to assess the contributions of each sex to this main effect (of focus). A main effect of focus on POC scores was found for women only (F(1,38) = 6.67, p < 0.014). Thus, the FL and FR men were unable to significantly change their POC scores according to focus group assignment; whereas, the women were able to do so according to the assigned focus ear. It appears that women alone contributed to the main effect of focus on POC scores. If anything, men diminished the main effect of focus, as all of their scores were similar, despite the focus group assignment condition.

Dichotic Listening

In order to assess dichotic listening ability, POC scores were first computed to view overall trends of ear dominance. Next, the number of correctly identified speech stimuli at each ear was analyzed [Table 5] for means and standard deviations of correctly identified stimuli at ear by sex, focus group, and trial. This was done to infer cerebral activation patterns and corresponding cardiovascular changes. The data were again analyzed in two design sequences.

Independent ANOVAs were performed on the two dependent variables obtained through the dichotic listening task- Dichotic Left and Dichotic Right. The first design was a sex (men, women) x focus (NO, FL, FR) x trial (pre-stress dichotic listening trial 1, post-stress dichotic listening trial1, pre-stress dichotic listening trial 2, post-stress dichotic listening trial 2) mixed design ANOVA. The main effect of sex was significant for Dichotic Left, (F (1,114) = 4.25, p < 0.04).

	Men		Women	
	Mean	SD	Mean	SD
LEFT EAR				
No Focus Group				
Pre-Stressor	8.3	3.7	9.5	2.7
Post-Stressor	7.9	3.0	9.2	3.1
Focus Left Group				
Pre-Stressor	8.0	2.6	10.5	4.2
Post-Stressor	8.6	3.0	10.3	3.8
Focus Right Group				
Pre-Stressor	8.5	3.7	8.2	2.3
Post-Stressor	7.7	2.8	7.8	2.3
RIGHT EAR				
No Focus Group				
Pre-Stressor	14.0	4.8	11.7	3.0
Post-Stressor	14.5	4.9	12.8	3.4
Focus Left Group				
Pre-Stressor	13.1	3.7	11.7	4.9
Post-Stressor	14.5	4.9	12.3	4.8
Focus Right Group				
Pre-Stressor	13.3	3.9	13.1	2.5
Post-Stressor	14.7	3.7	14.3	3.0

Table 5. Means and standard deviations of stimuli identified at the left and right ear by sex, focus group, and trial.

Women correctly identified speech sound stimuli presented at the left ear significantly more than men. However, there was also a main effect of sex for Dichotic Right, ($F(1,114) = 3.84$, $p< 0.05$). Men were able to identify significantly more stimuli at the right ear than women.

The main effect of trial was significant only at the right ear ($F(1,114) = 16.28$, $p < 0.0001$). Thus, accuracy in identifying stimuli presented to the right ear significantly increased after the cold pressor, whereas the cold pressor did not significantly increase left-ear accuracy of speech sounds identification.

Refined ANOVAs were performed separately for men and for women. The main effect of trial seen at the right ear was significant for both men ($F(1,57) = 8.14$, $p < 0.006$) and women ($F (1,57) = 8.19$, $p < 0.006$). Following the stressor, both men and women were able to significantly increase accuracy scores at the right ear.

For women, a main effect of focus on Dichotic Left was found ($F(2,57) = 3.42$, $p < 0.040$). Women in the different focus groups were able to shift their focus enough to significantly increase or decrease the number of speech sounds correctly identified at the left ear. Men were not able to do this, however, as explained previously, this might be partially due to ceiling effects.

The second design was a sex (men, women) x focus (FL, FR) x trial (pre-stress dichotic listening trial 1, post-stress dichotic listening trial1, pre-stress dichotic listening trial 2, post-stress dichotic listening trial 2) mixed design ANOVA. Again independent ANOVAs were performed on the dependent variables Dichotic Left and Dichotic Right.

A main effect of focus was found on Dichotic Left ($F(1,76) = 4.02$, $p < 0.049$). The number of stimuli correctly identified at the left ear by FL and FR participants was increased as a function of focusing on the specified ear.

Also, a main effect of trial was found on Dichotic Right ($F(1,76) = 11.66$, $p < 0.0010$). The number of stimuli correctly identified at the right ear by FL and FR participants increased as a function of the cold pressor.

Refined analyses of variance were then performed on the men and on the women of the FL and FR groups in order to assess the contributions of each sex to the main effects. Men evidenced a main effect of trial on Dichotic Right ($F(1,38) = 8.17$, $p < 0.0069$) where the number of stimuli correctly identified at the right ear by FL and FR men increased as a function of the cold pressor.

A main effect of focus on Dichotic Left was found for women ($F(1,38) = 6.50$, $p < 0.0149$). Women in the FL group were able to significantly increase accuracy at the left ear.

Self Report - Stress and Pain

At the end of the experiment, participants rated the level of stress and pain that they experienced from the cold-pressor. The scale was a 7 point scale, where 1 = not stressful at all, 4 = moderately stressful, and 7 = extremely stressful. The scores were analyzed using t-tests to assess group differences between men and women. No significant sex differences in stress or pain scores were found.

In order to assess what role hostility may play in the experience of stress and/or pain perception a sex (male, female) x group (high hostile, low hostile) ANOVA was performed on stress and pain scores. A sex x group interaction effect ($F(1,40) = 5.18$, $p < 0.0283$) on stress perception was found between level of hostility (high vs. low) and the self-reported perception of stress for each sex. High-hostile men reported experiencing significantly less stress than high-hostile women (Figure 3). No other effects were significant for stress or pain scores perception.

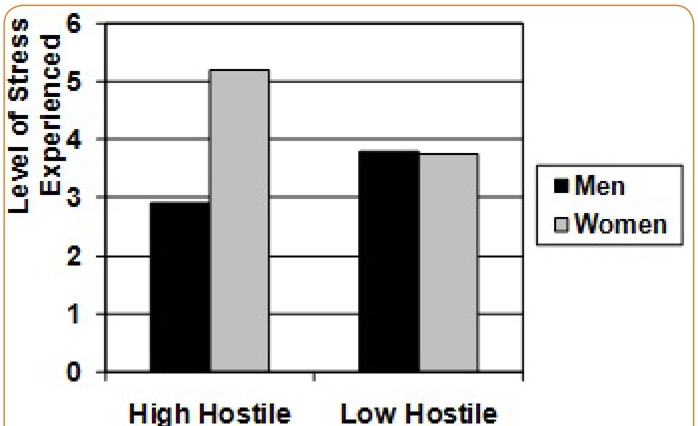

Figure 3. Sex differences in the level of stress experienced as a function of High or Low Hostility level.

Discussion

The current experiment was designed to explore sex differences on a measure of cerebral laterality (i.e. dichotic listening) that may affect cardiovascular reactivity to a cold pressor stressor. The experiment recorded dichotic listening and physiological data across different focus groups and between men and women prior to a cold pressor stressor and after a cold pressor stressor. The dichotic listening task was used to assess cerebral activation as a function of sex. A major focus of the experiment was to determine how a cold pressor stressor would influence dichotic listening performance in men and women. Changes in dichotic listening in response to the cold pressor were analyzed to determine how the stressor influenced brain activation. Physiological data were recorded in order to determine the implications of changing brain activation (as a result of experimental manipulation) on cardiovascular regulation in men and women.

The primary finding was a significant sex x focus interaction. Men who were in the FL group experienced significant increases in SBP compared to women who were in the FL group. This increase was not present in men or women in the other focus groups. The data provides additional support for the concept of functional cerebral space. Functional cerebral space postulates enhancement or interference of one activity by virtue of a concurrent activity [26, 25]. In the current experiment, dichotic listening interfered with SBP regulation in men who were in the FL group. Focusing attention to the left ear activated the right cerebrum and interfered with cerebral resources in the right hemisphere for regulation of blood pressure in men. This suggests that men may have more functionally specialized areas in the brain that led to dysregulation in one system when the neighboring system was activated. However, the absence of this effect in women suggests that women do not demonstrate the same degree of lateralization for dichotic listening at the left ear or for SBP regulation.

Additional support for a differing degree of hemispheric lateralization on dichotic listening tasks between men and women was provided by women's performance in the FL group. Women were able to identify significantly more dichotic sounds at the left ear relative to men, suggesting that women have more symmetry for verbal processing than men [37]. Moreover, women were able to dynamically increase accuracy at the right or left by focusing there attention to the respective ear. In contrast, men were not able to change the accuracy of dichotic sound identification as a function of focused attention to the right or left ear. The right ear advantage for speech sounds was prevalent across all focus groups for men. Increased functional asymmetry for language in men has been noted in other studies as well [20].

Further, the results indicated sex differences in blood pressure. Men evidenced significantly higher SBP, while women evidenced significantly higher DBP. Without a more detailed psychophysiological analysis it is difficult to speculate the cause of the sex difference in SBP and DBP. The data may be reflective of differences in the appearance and development of cardiovascular disease in men and women and suggest that future research examine both SBP and DBP when measuring sex differences in cardiovascular reactivity.

Differences in cardiovascular reactivity to the cold pressor and dichotic listening task were also found. Men were more reactive to the cold pressor compared to women. Increased cardiovascular reactivity has been related to increased rates of cardiovascular disease (CVD) and coronary heart disease (CHD) [28]. Increased reactivity in men may be indicative of a higher risk for the development of CVD in men. However, recent data suggest that CVD is the number one killer of women [1]. The fact that women are not as reactive in the laboratory may be a reason why they are often not identified as a population at risk for CVD or CHD.

Physiological measurements after the dichotic listening task revealed that men, but not women experienced a significant decrease in SBP. This may suggest that activation of the left hemisphere in response to verbal stimuli may increase parasympathetic control of the heart. Further, the fact that this effect was only found in men, suggests that sympathetic and parasympathetic control of the heart may be more lateralized in men.

The second major finding was that the cold pressor significantly increased accuracy at the right, but not the left ear in both men and women. This finding is indicative of a dynamic pattern of cerebral activation subsequent to a stimulus that increases arousal. A selective arousal pattern was present whereby brain areas in the left hemisphere were affected differently than homologous areas in the right hemisphere. Cerebral activation as a result of arousal thus, is not a global phenomenon, but rather a specific response to discrete stimuli.

The current study supports the idea that men have a higher degree of cerebral asymmetry for cardiovascular regulation and language function when compared to women. Sex differences in SBP and DBP should be considered as a factor in the different pathology that CVD and CHD have in men and women. Further, men scored significantly higher than women on the Cook Medley Hostility Scale. Heightened levels of hostility are associated with increased cardiovascular reactivity to stress [10] and may have played a role in the physiological data in the current experiment. However, the sex x group interaction for level of reported stress as a result of the cold pressor indicates that high hostile men reported experiencing significantly less stress than high hostile women. This may suggest that high hostile men were not aware of their physiological reactions to stress or it may be indicative of differential effects of hostility in men and women. Continued exploration of sex differences in hostility and the incidence of CVD are needed to determine what role the hostility construct plays in sex differences in cerebral organization and reaction to stress.

The current results provide support for dynamic functional cerebral laterality and highlight the importance of considering sex when looking at cerebral laterality. The data add to an increasing amount of data suggestive of sex differences in cerebral laterality [40]. Further, the results demonstrate that speech processing impacts the cardiovascular system. This may be especially relevant for therapy research. Speech could be used as a strategy for the regulation of cardiovascular processes during stressful situations. Patients undergoing cardiovascular rehabilitation may also be able to use speech to help control their cardiovascular responses. Additionally, it is possible that speech processing would affect other systems such as the emotional system or the somatosensory system. Future research may want to address what role speech plays in the ability to perceive or express emotion or how speech influences perception of somatosensory events.

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